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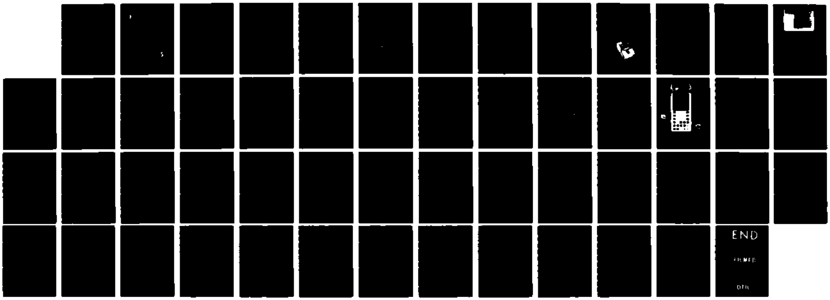

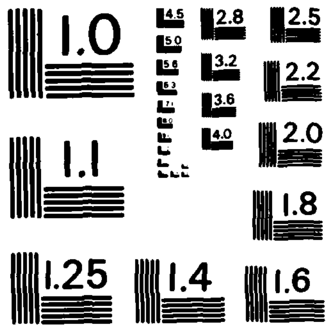

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Technical Note 4-85

A STUDY OF DATA ENTRY KEYBOARDS: THE 4 X 4 KEYPAD

Rodger J. Koppa

June 1985

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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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Research concerning the layout of keypads for data entry was briefly surveyed to determine what conventions exist suitable for inclusion in MIL-STD-1280 (military standard on keyboard arrangements). The calculator layout (bottom-up) is preferable to the telephone layout (top-down). More research is needed to establish the best methods of denoting key mode selection. Industry conventions have dictated the location of function

keys, but more research is necessary to verify these locations. Chord keyboards are an alternative, but they have specialized uses and are not recommended for low-skilled operators.

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A STUDY OF DATA ENTRY KEYBOARDS: THE 4 X 4 KEYPAD

INTRODUCTION

Background

Largely through the efforts of the U.S. Army Electronics Command, the U.S. Department of Defense adopted MIL-STD-1280 in January 1969 as the definitive guideline for keyboard arrangements. At the time this standard was written, punch cards were still predominantly used for data entry, and only a few systems were interactive with teletype machines. Since 1969, developments in data entry have multiplied, and there is a pressing need to revise MIL-STD-1280 to include new or advanced keypad layouts.

In 1969, the IBM Selectric typewriter was only a few years old, and keyboard layouts were geared toward the typewriter. The term word processing had not even been coined yet. The first practical hand-held calculator was still two years away; numerical keyboards were found in two forms: the ten-key adding machine, and one which featured multiple columns of number keys (e.g., the Friden calculator or Marchant Keyboard (Figure 1).

Courtesy Marchant Calculators

Figure 1. The classic 10-key adding machine.

Only a few telephone subscribers had what would become the standard of the industry--the Touch-Tone® telephone with a key arrangement adopted after considerable research by human factors engineers at Bell Telephone Laboratories. Considering the technology of 1969, it is not surprising that MIL-STD-1280 omitted mentioning a small, number-entry oriented array, commonly referred to as the 4 x 4 keypad, designed to be hand-held and operated with one hand.

Since the 1960s, the role of troops in the Armed Forces has evolved from the traditional dependence on firearms and manual labor to the increasing use of sophisticated weaponry and information transfer equipment, often in well-equipped mobile fire control units and command posts. The problem with the electronic systems being built is that the data entry and transfer equipment provided in these command posts is built by different manufacturers or even by different operating units of the same manufacturer. Although these systems perform similar or even identical functions, they have different data entry keyboards or have similar keyboards whose keys accomplish different functions.

Faced with this situation and realizing that many future weapon systems will use keypads for various kinds of data entry (even under field combat conditions) the U.S. Army Human Engineering Laboratory (HEL) contracted with the Texas Transportation Institute, Human Factors Division through the Texas A&M Research Foundation to conduct a brief literature survey on current small keypad layouts.

OBJECTIVE

The purposes of this literature search are to survey the available research and applications data on the 4 x 4 keypad as a data entry device, to recommend that design specifications for the small keypad be added to MIL-STD-1280, and to identify further research that might be required for future guidance on keypad design.

The HEL restricted the scope of this study to the small one-hand data entry keypad, i.e., the data entry device with fewer keys than the standard typewriter keyboard. Some of these arrays are really 4 x 3; some are as complex as the keypads of programmable calculators.

METHOD

The literature search was limited to studies and reports after the mid-1950s, when data entry by keyboard became more common. Primary information was provided by three human factors journals: Human Factors, Ergonomics, and Applied Ergonomics. Following this preliminary search, the Automated Information Retrieval System (AIRS) of the Sterling Evans Library, Texas A&M University was used with the key words and word combinations listed in Table 1 for two data bases: (1) National Technical Information Service (NTIS) which contains nearly all government-funded project reports, and (2) INSPEC, which is the largest English-language data base for physics, electrotechnology, computers, and controls.

TABLE 1

Key Words and Combinations used for AIRS Literature Search

Keypad; key pad; keyboard
Keyboard or key pad or keyboard
Tone pad; data entry; qwerty
Data entry or qwerty
Keyboard and numeric entry
Human factors or ergonomics and data entry
Keyboard layout or keyboard design
Keypad or key pad layout or design
Keypad or keypad and data entry or human factors or ergonomics or layout or design

RESULTS

History of Keypads

Although mechanical and electromechanical calculating devices like adding machines and cash registers used numerical keypad arrays as far back as the 1920s (Figures 1 and 2 show two early types of calculating machine keyboards), the real ancestors of the modern keypad that is used for single-hand data input are the hand-held calculator (beginning in the early 1970s), the Touch-Tone® keypad that replaced the familiar telephone rotary dial in the middle 1960s, and the auxiliary keypads that have been incorporated in full keyboard data entry terminals and teletypes since the late 1960s. All of these key arrays are single-entry or use only a shift key to allow more than one character for a key input.

The stenotype machine used by court reporters is a chord keyboard--an entirely different keyboard that has not been seriously used for data entry except for specialized devices like the stenotype. Multiple function keypads approach the chord concept in some applications. The mail services in Canada, England, and the United States use chord keypads for mail sorting.

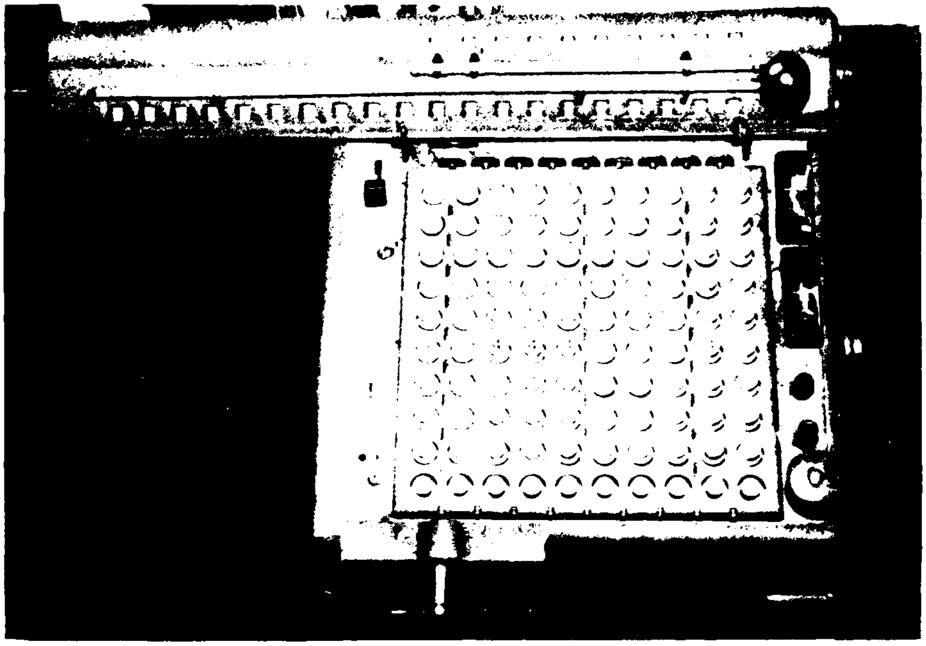


Figure 2. Full decade comptometer keyboard.

The keypad arrangement of even the earliest electronic slide rules or calculators used the same basic ten-key arrangement of the electromechanical adding machines, the so-called bottom-up array in which the numbers are arranged as follows, with various locations under columns 1, 2, or 3 for 0:

7	8	9		7	8	9		7	8	9
4	5	6		4	5	6		4	5	6
1	2	3		1	2	3		1	2	3
	0			0						0

Function or verb keys are located on the periphery of this array in layouts that varied even from model to model by the same maker (in those days, either Texas Instruments or Hewlett-Packard). Considerable in-house research was carried out by these makers to support their layouts, but little of this early work has ever been published.

Before much of the work by calculator manufacturers, a series of important studies was performed by Deininger (5) of the Bell Laboratories to establish the keypad array for the successor to the dial telephone of the 1890s. A number of different layouts were tried, some more as straw men than as serious contenders, including some circular arrays borrowing from the obsolete dial arrangement.

Figure 3 shows the arrays investigated by Deininger. The calculator array associated with Deininger (Array I-A) was not included in his second set of studies because it was eliminated for being inferior in keying time to the other two arrays it was grouped with; however, direct comparison of this array with the one ultimately chosen for the telephone indicated that mean keying time differed by only 3.25 percent with the telephone array being superior (5.08 seconds versus 4.92 seconds).

Keypads with full keyboards have generally followed the adding machine or calculator arrangement. A survey of computer magazines like Computers and Electronics, BYTE, and Personal Computing failed to identify a single modern computer with an auxiliary keyboard which uses the telephone keypad arrangement although it is probably the most familiar keypad array:

1 2 3

4 5 6

7 8 9

0

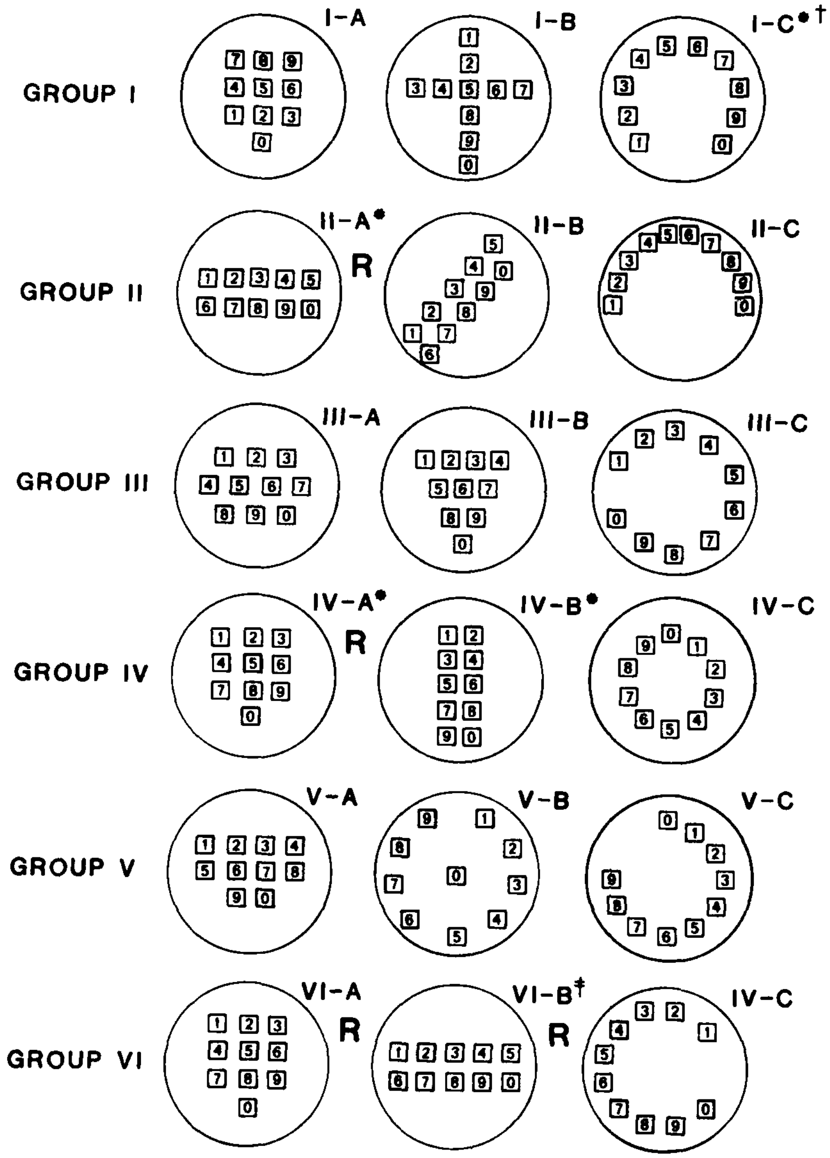
Some electronic cash registers that serve as remote terminals use the telephone keypad arrangement. So far, no standards for keypad arrangements exist. Although there are similarities in keypads, every keypad differs in some ways from other designs.

MAJOR ISSUES IN KEYPAD LAYOUT

Top-down (Telephone) Versus Bottom-up (Calculator) Layouts

The issue of top-down versus bottom-up layouts goes back at least to 1955 and a study reported by Lutz and Chapanis (9). This study focused on expectancies for numeric and alphabetic designations of keys on keypads in which a number of different arrays were used (Figure 4). Subjects marked a test booklet with their expectancies of which blank key was associated with which number or letter. The telephone layout for numbers was chosen most frequently, and over 50 percent of the subjects laid out a blank keypad for telephone configuration, in that way. Only 8 percent chose a calculator layout even though ten-key adding machines were very common in 1955. Alternative layouts approximating the telephone layout were also chosen with relatively high frequency, as compared to the calculator layout.

Different keypad arrangements on prototype telephones were compared using subjects as their own controls, with each session involving two to five different arrangements. Subjects, all Bell employees, keyed 10 to 15 different telephone numbers each session on each set. Accuracy and keying time were recorded, as well as preferences for layout. The actual differences between the top-down arrangement versus the bottom-up arrangement were very small, and only with respect to mean keying time, 5.08 seconds versus 4.92 seconds per number.



Note: R = repeated version

Figure 3. Deininger's arrays (1960).

1	2	3
4	5	6
7	8	9
	0	

1	2	3	4	5
6	7	8	9	0

1	2
3	4
5	6
7	8
9	0

These three arrays were the most frequently chosen.

	0	
7	8	9
4	5	6
1	2	3

1	4	7
2	5	8
3	6	9
	0	

1	6
2	7
3	8
4	9
5	0

These three were the next most frequently chosen.

Figure 4. Arrays chosen in the study by Lutz and Chapanis (1955).

Deininger provides no evidence against adopting the top-down or bottom-up arrangements relative to error rate; however, a within-groups comparison found the top-down arrangement superior in keying performance and preference. This finding and the engineering advantages offered by the rectangular arrangement supported adoption of the top-down arrangement by the Bell system.

In 1965 Paul, Sarlanis, and Buckley (11) reported in a study for the Federal Aviation Agency a comparison of two experimental 16-key keyboards: the telephone configuration and the calculator arrangement. The subjects in the matched-groups design were air controllers with various levels of typing ability. Superior performance on the telephone (top-down) keyboard was reported for both alphanumerics and for letters alone. No significant differences were found for numeric keying only.

In a study published in 1968 using British housewives, Conrad and Hull (4) found important speed and accuracy differences in favor of the telephone layout as opposed to the calculator layout, especially regarding accuracy. It was further reported that the differences were probably, in part, due to the subjects' expectations concerning the placement of the numbers on the telephone layout.

Klemmer (8) in his 1971 review of top-down versus bottom-up layouts concludes that the telephone arrangement with 1, 2, 3 across the top row is preferable to the adding machine arrangement with 7, 8, 9 across the top, especially for low-skilled operators. He suggests that new devices have 1, 2, 3 across the top of the 3 x 3 plus zero array.

Seibel (14) summarizes earlier findings by stating that a practiced data entry operator will perform equally well with either the 1, 2, 3 or the 7, 8, 9 arrangements. The difference in arrangements becomes important for an operator who only makes occasional entries or alternates between using different arrangements. Alternating between two different arrangements should be avoided. He concludes that the 1, 2, 3 arrangement is faster and more accurate than the 7, 8, 9 arrangement for the unskilled operator.

There are several articles and reports to indicate that aircraft keypads in the United States and United Kingdom use the telephone top-down format, as does the National Aeronautics and Space Administration aboard the space shuttle (10). There also exists a NATO Standard, STANAG 3869AI which calls for a 3 x 3 + 1 matrix with keys 1, 2, 3 on the top row.

In Woodson's Human Factors Design Handbook (18), he states that data entry keyboards have been somewhat standardized without consulting known research which considers human operators and their ability to use different key arrangements Conventions within industry create powerful constraints against applying what might be considered a more efficient organization of the keypad. Figure 5 illustrates the current data entry keypad. Basically, it represents a principle of reading from the bottom to the top.

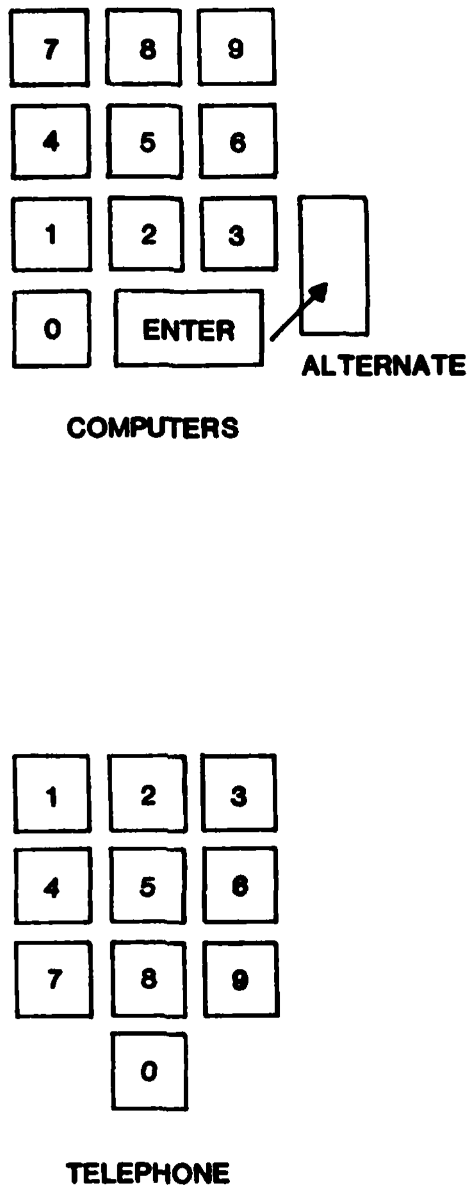


Figure 5. Woodson's keypad layouts.

On the other hand, keyboards used in communications have typically been laid out to conform with recommendations made in human factors research on keyboard arrangements; communications keyboards read from the top to the bottom and from the left to the right.

Woodson does not recommend that the data entry keypad arrangement be changed, but he does note discrepancies that may influence the design of newer keyboards:

1. Although the numbers are read systematically from bottom to top, the zero and final entry is at the bottom; i.e., normally the zero is the final digit entered prior to entry.

2. It is normal to read from the top down; thus typical data entry causes extra initial search.

Location of the Zero Key on a Keypad

A subissue related to the bottom-up versus top-down keypad layouts is the location of the zero key. In the Lutz and Chapanis (9) study of expected locations of digits, it was reported that in the most frequently chosen number arrangement where there was an extra circle, i.e., in the 3 x 3 + 1 configuration, the zero was always placed in that circle. In this case and where there was no extra circle, the zero always followed the 9 and never preceded the 1.

Conrad and Hull (4) concurred in their report of the preferred layout for numerals stating that the telephone (top-down) layout conforms more to subjects' expectations of where numerals are to be found with respect to each other. By far the largest single keying error occurs with the calculator (bottom-up) keyboard when subjects strike "0" when "1" is required, i.e., they go to the end of the configuration. With the telephone layout, this occurs no more often than would occur by chance.

The standard typewriter, QWERTY keyboard, has always placed the zero following the nine.

Conrad (3) conducted a study which investigated the role of short-term memory in the design of data entry keyboards. When a numerical data entry keyboard has a key layout which is poorly compatible with normal expectations of where the digits are located, the results of this study showed that the subjects required more time to locate each key, which is associated with an increase in recall errors for material held in memory during keying. More research needs to be conducted in this area.

Alphabetic and Symbolic Data Entry

The effect of keyboard layout on entering alphabetic and symbolic (e.g., operation) data has been discussed. Telephone use of keypads has concentrated on the input of numerics. If a keypad is to be considered for data entry on a computer, then provisions for symbols other than numbers must be made. The studies dealing with telephone usage could approach this rather simply since for this use, the alphabetic symbols were the same as those used for dial telephones with numbers. Early telephone applications placed the zero in the center column of keys, with space reserved for two special symbols on either side in columns one and three. These special symbols have come to be "*" and "#" which are in use in modern exchanges which use a central computer.

Other layouts and multipurpose usage of numeric keys have been investigated in the last 25 to 30 years. In the second part of the Lutz and Chapanis (9) study, the investigators used a set of blank key arrays and gave subjects instructions to supply the letters of the alphabet, except Q and Z (following telephone practice) on the blank keys as they might expect to find them on a real keypad. Most frequently, the letters were placed in order in horizontal rows beginning with the top row. No matter what the configuration of the keys, this lettering system was chosen by about one-third of the 100 subjects. Two or three letters were usually in order on each circle, which represented the keys on the keypad. Once again, the telephone layout was expected by a majority of the subjects. The authors concluded that people expect to find letters on the keyset arranged from left to right with two or three letters in order on each key in horizontal rows, starting with the top row for all of the six configurations of keys tested. Even when numbers were supplied (i.e., 1, 2, 3 versus 7, 8, 9 at the top) and expectancies for letters were asked for, subjects were evenly divided between arrangements that followed the numbering layout and arrangements that adhered to the expectancies of left-to-right and top-to-bottom.

Desautels (6) and his associates studied keypad data input techniques in which information was alphanumeric to evaluate the capability of using the standard telephone keypad for data entry. Their opinion was that the 4 x 4 keypad would not likely become as well-known or used as the 12-key pad. Desautels postulated that all applications data and control inputs (verbs) would be numeric, using a code book if non-numeric data had to be entered or some other special technique (such as holding a special key down while encoding with the other numeric keys). Desautels also discusses a Cornell University proposal for a 12-key device, which is pictured in Figure 6. In this application, the software (CUPL--Cornell University Programming Language) is configured to interpret ambiguous input by context and position of the characters in a string. The user of this keypad continues without using explicit codes to context. Only the key (row) 3, (column) 4 labeled END OF LINE is unambiguous. The more orthodox approach uses some kind of code matrix (see Figure 7).

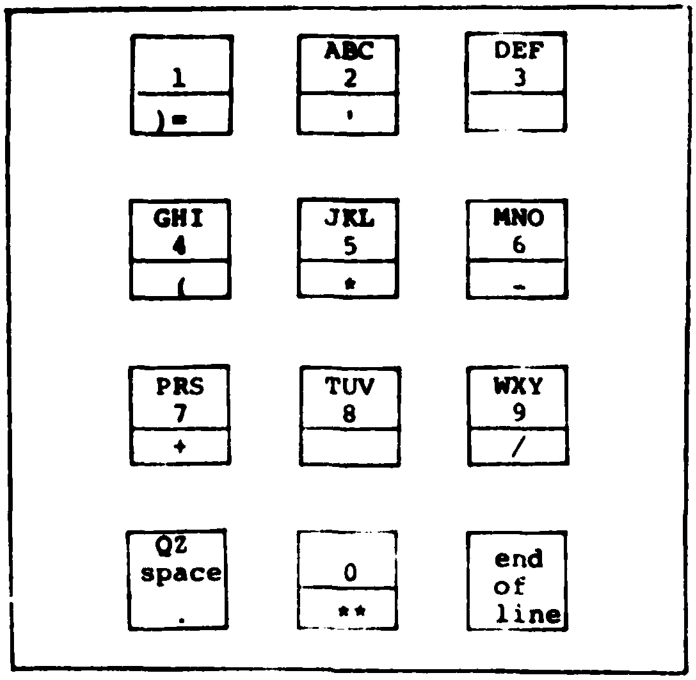


Figure 6. The Cornell Tele-CUPL keypad.

SECOND DIGIT

FIRST DIGIT	1	2	3	4	5	6	7	8	9	*	0
1	SPACE 040	Q 121	Z 132	EOT 004	q 161	z 172	< 074	> 076	DC1 021	(050	1 061
2	A 101	B 102	C 103	a 141	b 142	c 143	[133	] 135	DC2 022	* 052	2 062
3	D 104	E 105	F 106	d 144	e 145	f 146	{ 173	} 175	DC3 023	) 051	3 063
4	G 107	H 110	I 111	g 147	h 150	i 151	~ 176	| 174	DC4 024	CAN 030	4 064
5	J 112	K 113	L 114	j 152	k 153	l 154	^ 136	_ 137	NAK 025	SO 016	5 065
6	M 115	N 116	O 117	m 155	n 156	o 157	` 140	\ 134	SYN 026	' 047	6 066
7	P 120	R 122	S 123	p 160	r 162	s 163	NUL 000	SOH 001	STX 002	ETX 003	7 067
8	T 124	U 125	V 126	t 164	u 165	v 166	ENQ 005	LF 012	ACK 006	BEL 007	8 070
9	W 127	X 130	Y 131	w 167	x 170	y 171	HT 011	VT 013	DEL 177	BS 010	9 071
*	+ 053	= 075	/ 057	! 041	" 042	# 043	$ 044	% 045	& 046		. 056
0	, 054	- 055	SUB 032	? 077	: 072	; 073	BS 010	SI 017	DLE 020	ESC 033	0 060

designates end-of-input
*** designates command

Figure 7. Paired Touch-Tone® to ASCII code conversion table.

Many speech-disabled people, for example, those with severe cerebral palsy, are beginning to use codes like this with considerable success. With practice, the occasional user could use these types of codes for routine data input.

Smith and Goodwin (15) reinforce the points made in the Desautels study concerning single-mode software interpretation of alphanumeric entry in an analysis of single-stroke alphabetic entry using the standard telephone keypad. A study by Kramer (1968) indicated that high error rates in data input result from the use of a constrained keypad with multimode keys. Since 1968, using computers and hand-held calculators with multiple function keypads is standard practice.

A different approach to alphabetic character entry has been proposed by Sidorsky, as reported by Alderman and his associates at the U.S. Army Research Institute for the Behavioral and Social Sciences (2). This recent paper describes a 1974 proposal for an alpha-dot 5-key keyboard or pad. The keys to be pressed depend on the shape of the alphabetic (or even numeric) character to be entered, according to a schema illustrated in Figure 8. A "handprint' input keypad is also possible with this approach, as shown in Figure 8. This keypad is really a type of chord keyboard. Sidorsky and some investigators in Israel have shown that enlisted personnel can quickly master this input strategy and there does not appear to be any reason that this approach could not be used with a standard keypad.

Another approach for some special-purpose devices has been to arrange multimode keys around the numeric-only keys. These keys are primarily function keys, but pressing a mode select key activates one or more functions for these keys. This approach is illustrated by the Datamyte, a time-and-motion data collection microprocessor. One of several keyboards available on this device is illustrated in Figure 9.

Another multimode key approach which begins to resemble a standard keyboard is used by Observational Systems, Inc., whose time-and-motion study microprocessor keypad (OS-3)® is shown in Figure 10. A shift key selects as many as four different modes for many of the keys. Both the Datamyte and the OS-3 use the bottom-up calculator numeric array. Data comparing this keypad to the others regarding input errors or speeds are lacking. The latest version of the Hewlett-Packard CV41 programmable calculator uses a keypad approach much like the OS-3, but the alphabetic layout is in alphabetical order from top to bottom (Figure 11).

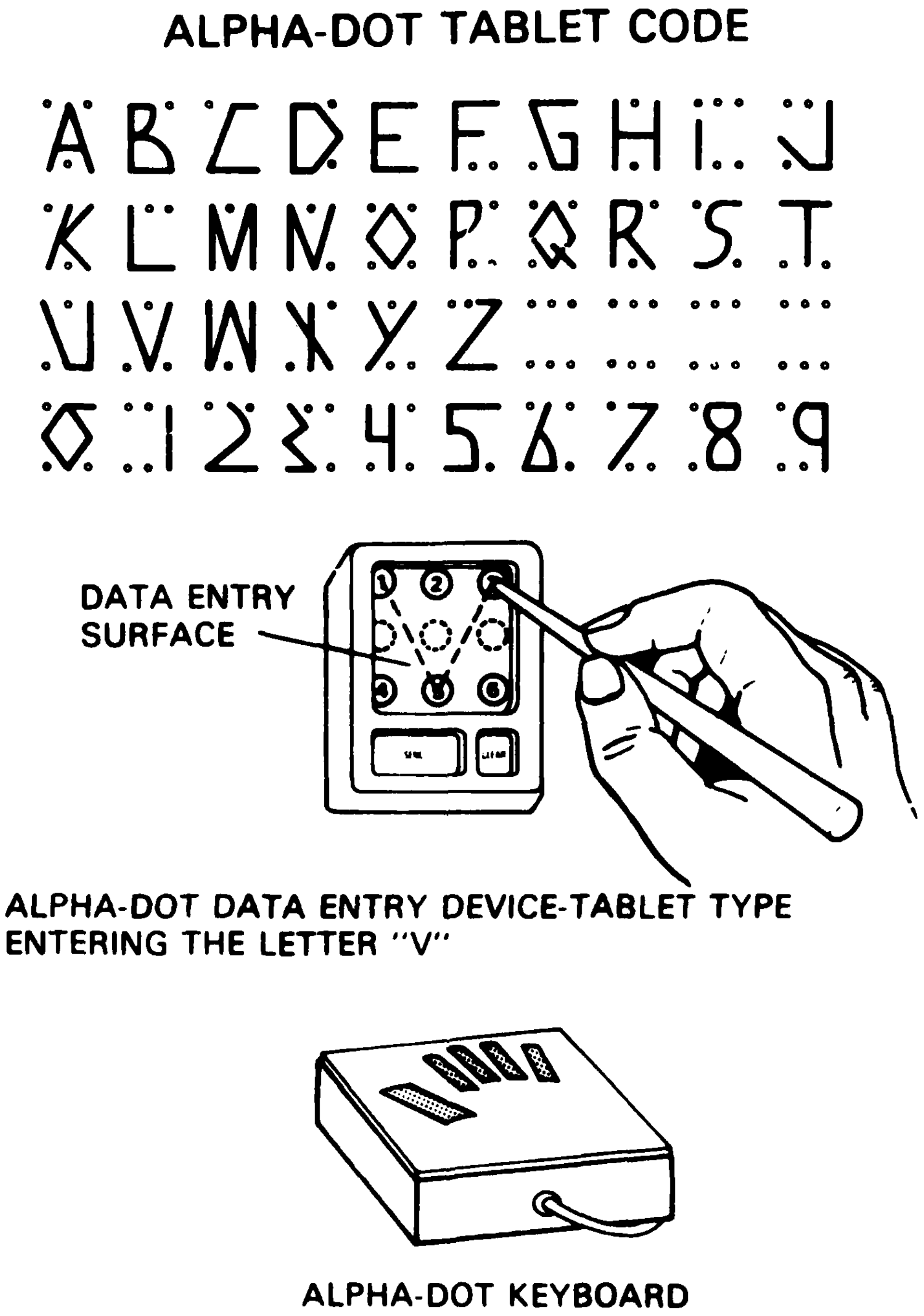


Figure 8. The alpha-dot code and two types of entry devices. (Sidorsky, 1974, 1979)

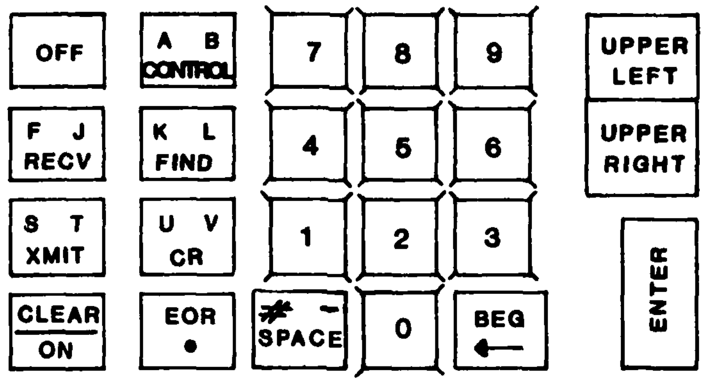


Figure 9. A standard data collector keypad.

Provision and Location of Function Keys

Function keys can be arithmetic operator keys (e.g., "+," "-," "*," and "/"), found on any calculator, or CURSOR, ENTER, RETURN, DELETE, CLEAR keys or special purpose keys that may be designated through an operating or utility software system.

A search of all the articles and papers gathered for this study uncovered only a few that had information relevant to the provision and location of function keys. In Project Green Thumb (a computer-based management system for farmers which used a simple keypad terminal), Warner and his associates (17) used a column of special function keys to the right of the standard telephone array. In a paper written for the International Conference on Man-Machine Systems, Fletcher (7) identified the following functions that must be included with a hand-held keypad: cursor control, elementary word processing, and direct control of certain peripherals. Including alphanumerics and some symbols, Fletcher says that 120 codes need to be handled with such a device. He suggested a layout consisting of 4 subarrays, well beyond the scope of this study. The layout requires many dual-purpose keys, even when 60 separate keys are provided (see Figure 12).

In the absence of definitive studies on the placement of function keys (there were plenty of articles on different functions, especially software-designated ones), the project staff at Texas A&M decided to make a brief foray to the local computer stores to capture present industry practice. Their logic was that the Army computer operators will begin to use such machines within the next few years. The goal was to find out what agreement existed regarding the layout of special function keys.

Figures 13 through 23 illustrate these keypad field studies. Most of these keyboards were auxiliaries of large keyboards, but a few were independently functional. Figure 24 maps the function keys and numeric keys onto a 6 x 6 matrix. A study of this diagram reveals some trends in layout that can be highlighted if one considers that a double-size key can be assigned to more than one position on the matrix. For example, if a particular layout (Figure 20) has a double-size ENTER key, an E will appear on two adjacent keys on the diagram. This re-mapping is shown in Figure

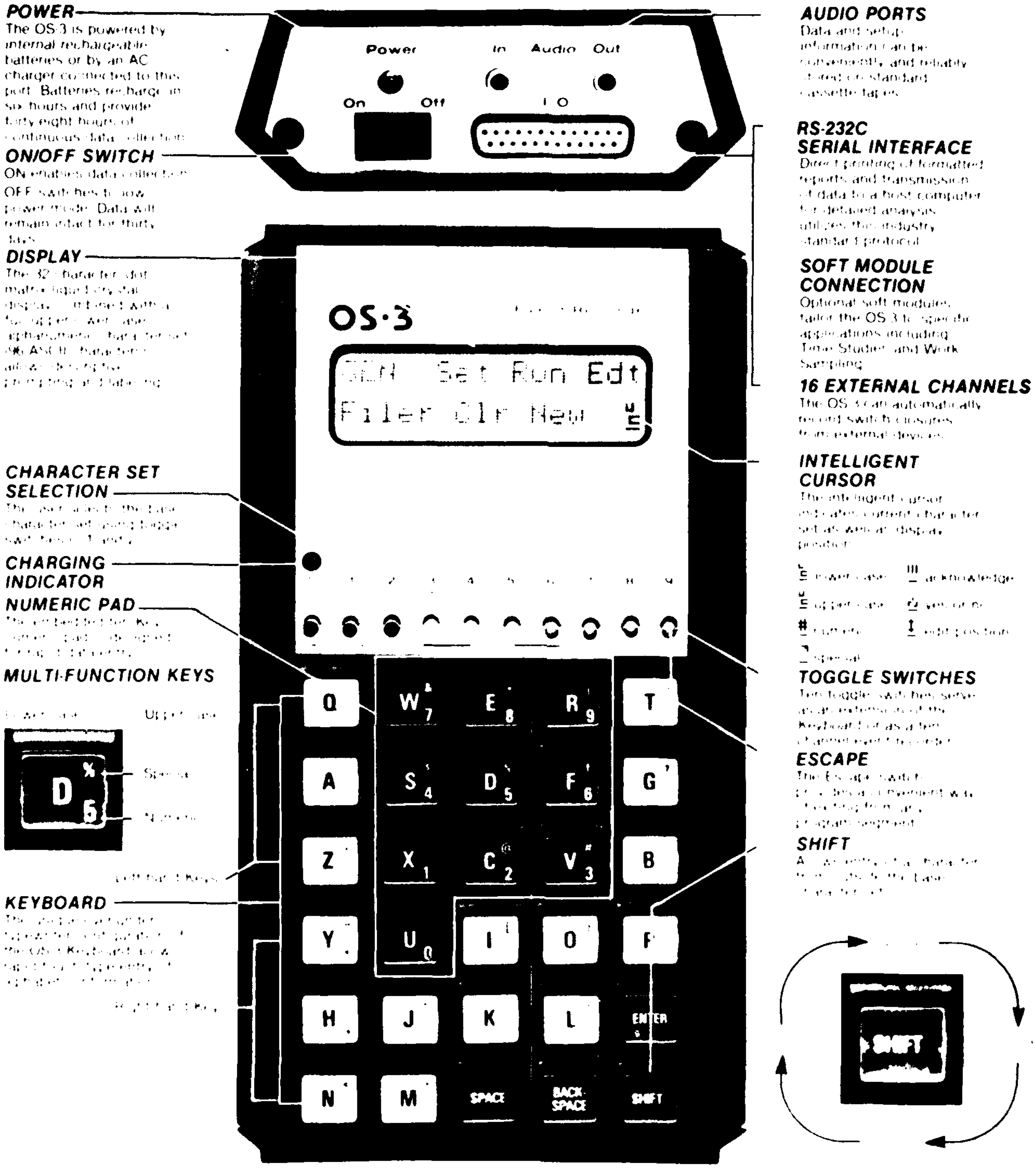


Figure 10. The OS-3 Event Recorder ®.

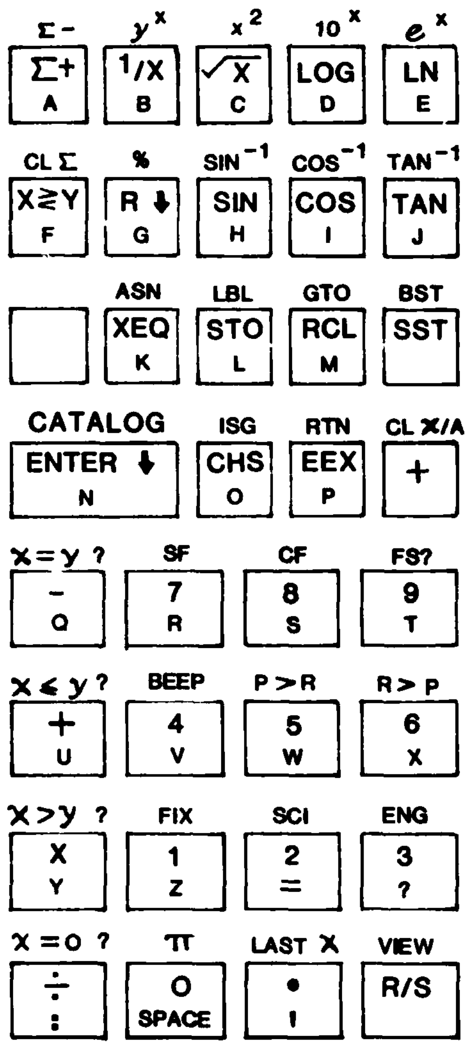


Figure 11. A complex calculator keypad.

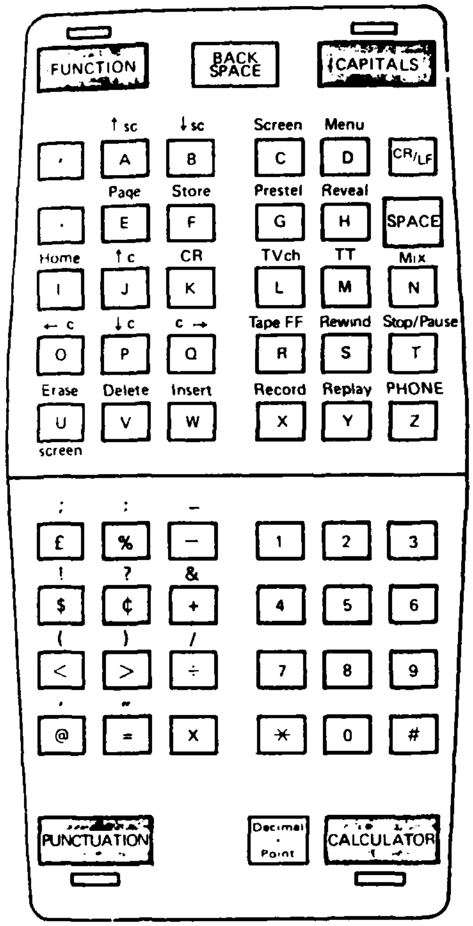


Figure 12. Fletcher's keypad.

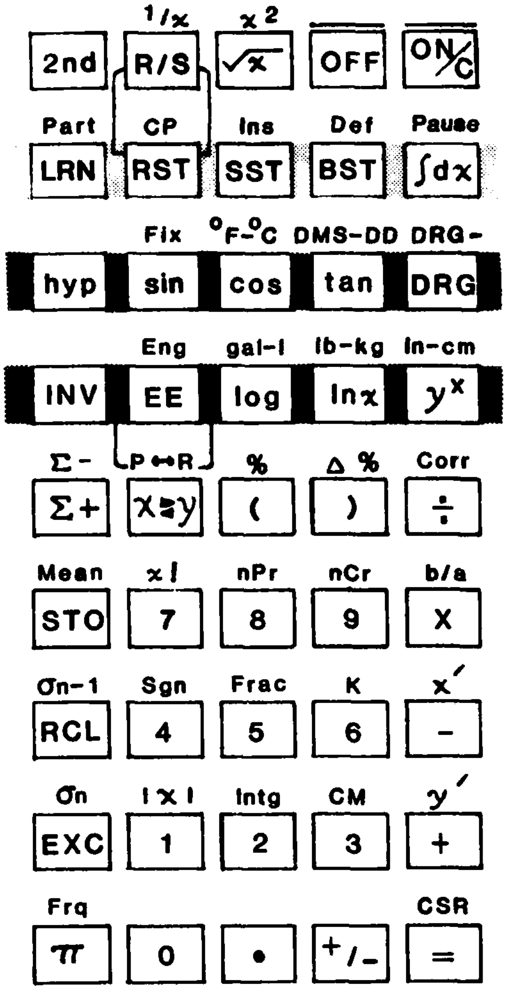


Figure 13. A basic 45-key calculator keypad.

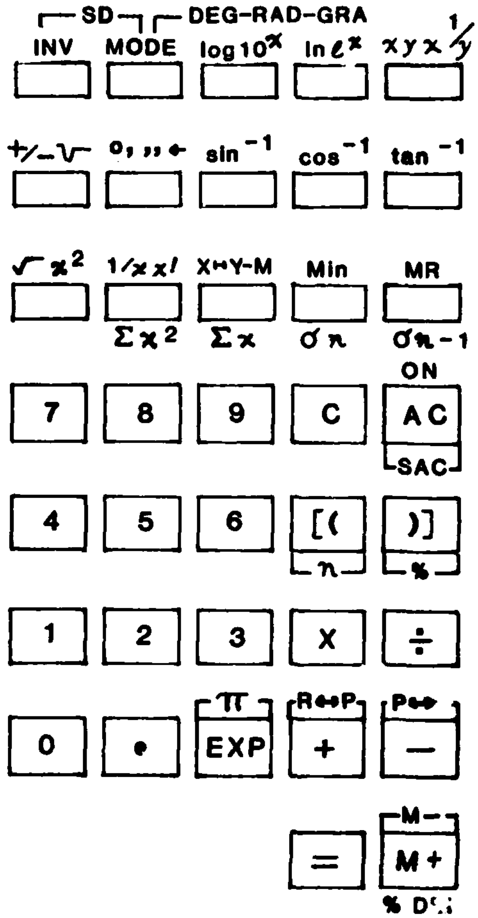


Figure 14. A simple 37-key calculator keypad.

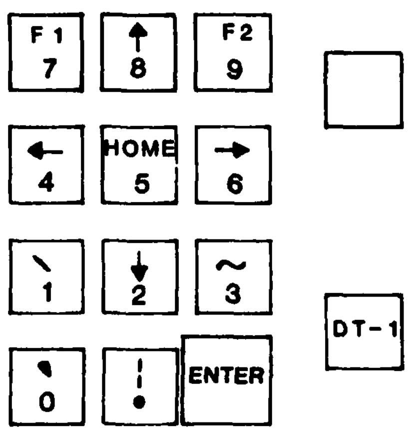


Figure 15. A basic auxiliary data entry keypad for use with a microcomputer.

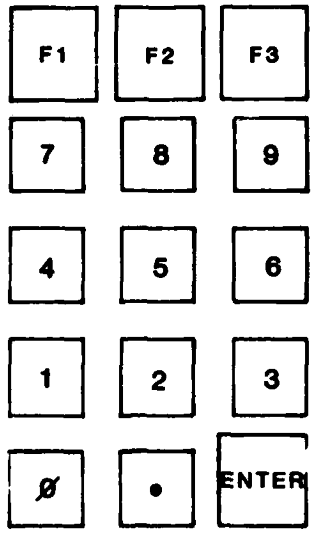


Figure 16. An auxiliary data entry keypad: Example 1.

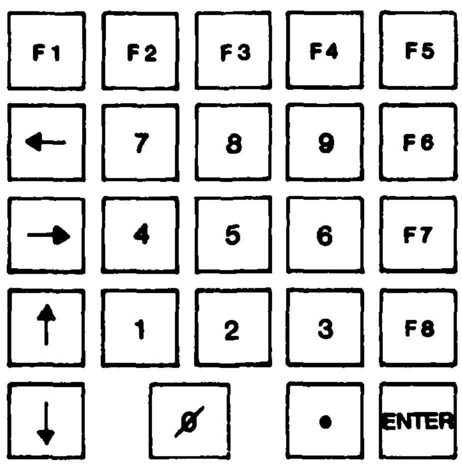


Figure 17. A more complex auxiliary data entry keypad: Example 2.

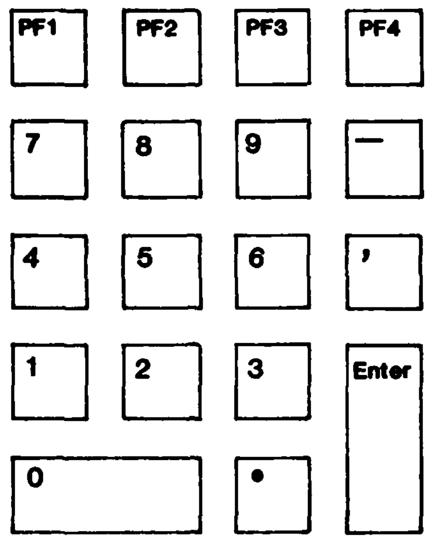


Figure 18. An auxiliary data entry keypad: Example 3.

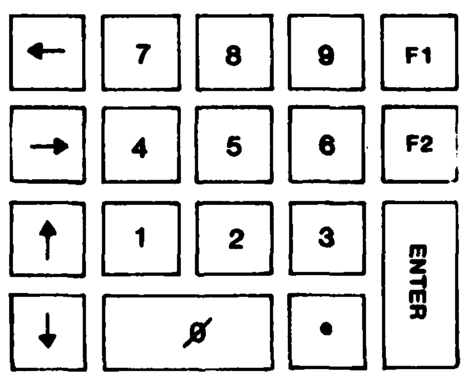


Figure 19. An auxiliary data entry keypad: Example 4.

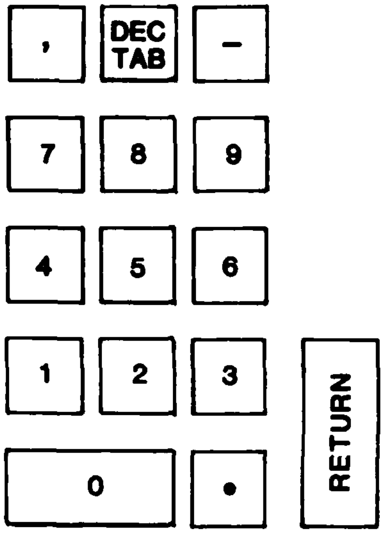


Figure 20. A basic auxiliary data entry keypad: Example 5.

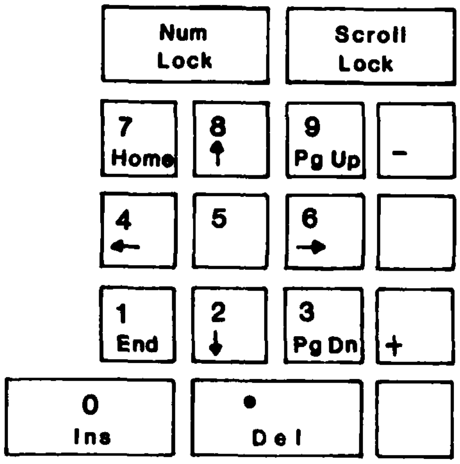


Figure 21. A basic auxiliary data entry keypad: Example 6.

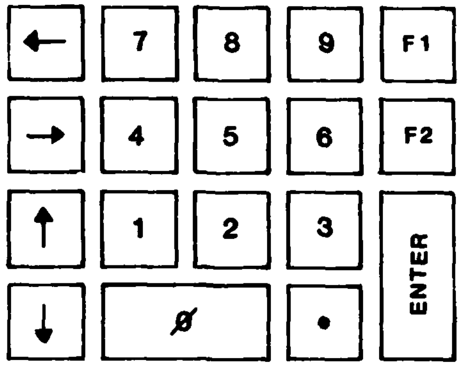


Figure 22. A more complex auxiliary data entry keypad: Example 7.

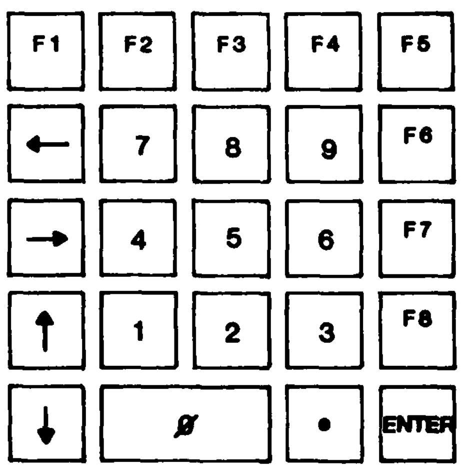


Figure 23. A more complex auxiliary data entry keypad: Example 8.

F1	F2 9 F1	DEC TAB F3 F2	F4 F1 - F3	F5 ÷ F4	
	F1 7	, 8	F2 9	F6 - - X	
	4	HOME 5	6	F7 9 - F1	F2
	1	2	3	F8 X + ENT	+ +
	* Ø Ø Ø	Ø	ENTER • # • DEL	ENTER + = ER F	-
				=	F

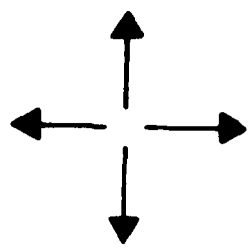
Figure 24. Auxiliary keypad function and numeric key mapping on a 6 x 6 matrix.

25. All functions found on these different layouts are circled; symbols and numbers are not. If all functions are taken (without elaboration), Figure 26 results, a matrix scattergram with tick marks for numbers of functions assigned to a particular key. Functions clustered across the top and down to the right side of numeric array (which incidentally are all bottom-up configurations), with the most popular function key being 5, 5. The next most frequent function-key positions are 3, 5, and 1, 3. The mapping that retains the double-size key assignments (Figure 24) shows that 0, ENTER, "+" are often doubled in size. ENTER, or a variant like RETURN, generally appears at the lower right corner of the numeric array, under the 3.

A 4 x 4 or 5 x 4 keypad emerges as the consensus keypad. The 4 x 4 is shown in Figure 27. This layout places the most important function key, F1, at the location most used in industry for functions. The second most important or used function is assigned to key 2, 4. The third most important or used function is assigned as shown. The 5 x 4 keypad is shown in Figure 28. In both of these layouts, certain numeric keys also have minor function identification. If only a 4 x 3 telephone pad is available, the consensus layout would lead a designer to the layout sketched in Figure 29.

In this layout, the most used or needed function is found in the usual spot, 4, 3. The 6 key is the next most-used function, followed by key 8. If a larger keypad were used, the bottom middle key, next to 0, would be a third-level function, but this nonnumerical key ought to be a first-level or at least second-level function. Other keys not designated for function use on this layout would be fourth in priority of use. No special provision for the shift function is given on any of these keypads.

Figure 24 shows a particular function which is not considered in later figures. That function is cursor control, the two or four keys needed to move a pointer around the display. Some keypads handle cursor control with two keys, with a shift function to reverse their direction, but most use four keys. The much-preferred, cross-shaped design requires dual function keys when there are few keys available on a small keypad.



Some manufacturers place these special keys to the left of the numeric pad. Isolating cursor keys from keys which perform arithmetic or logical operations, or transform the data is a good idea.

An article in <u>BYTE</u> magazine describes a general-purpose standard keyboard which includes a keypad, the Human Applications Standard Computer Interface (HASCI). The HASCI keypad is the product of a multiyear study of keypad design by Rutkowski (12). The Epson QX-10® computer uses this layout shown in Figure 30. This design is similar to the consensus keypad.

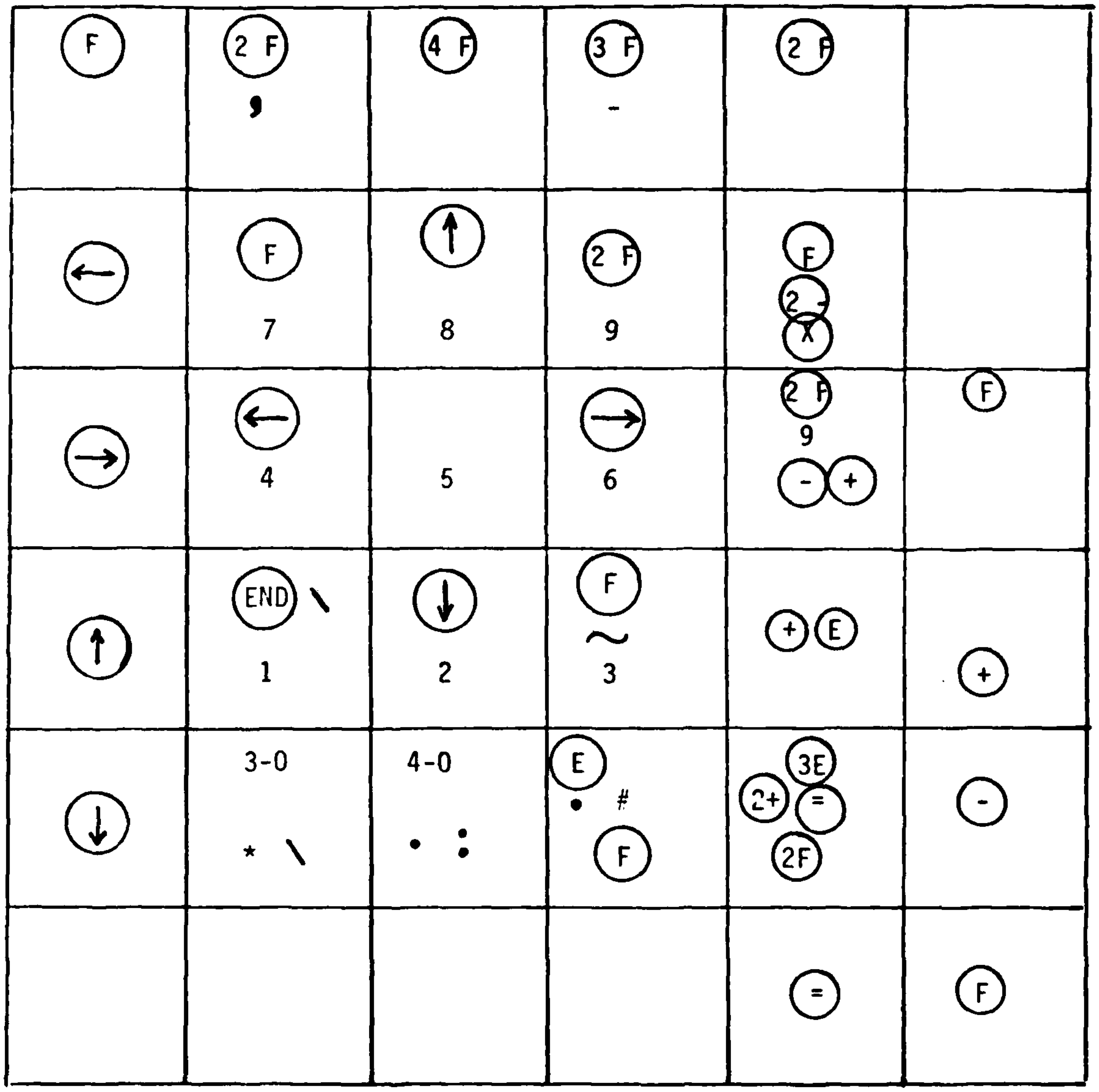
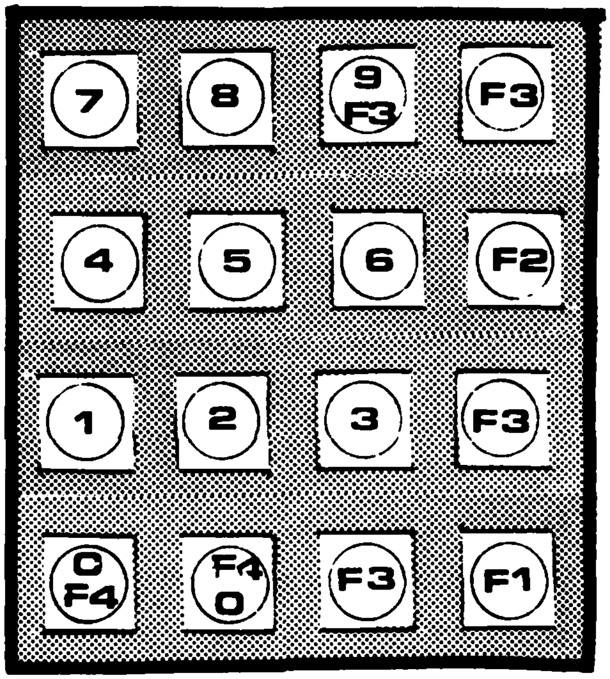


Figure 25. Auxiliary keypad double-key re-mapping.

1	11	1111	111	111	
	1 7	8	11 9	11	
	4	5	6	1111	1
	1 1	2	1 3	11	1
	Ø	Ø	11	11111111	1
				1	1

Figure 26. A matrix scattergram of function and key placement (tick marks indicate numbers of functions assigned to particular keys).



Functions (F n) are in descending order by n

Figure 27. Consensus 4 x 4 keypad.

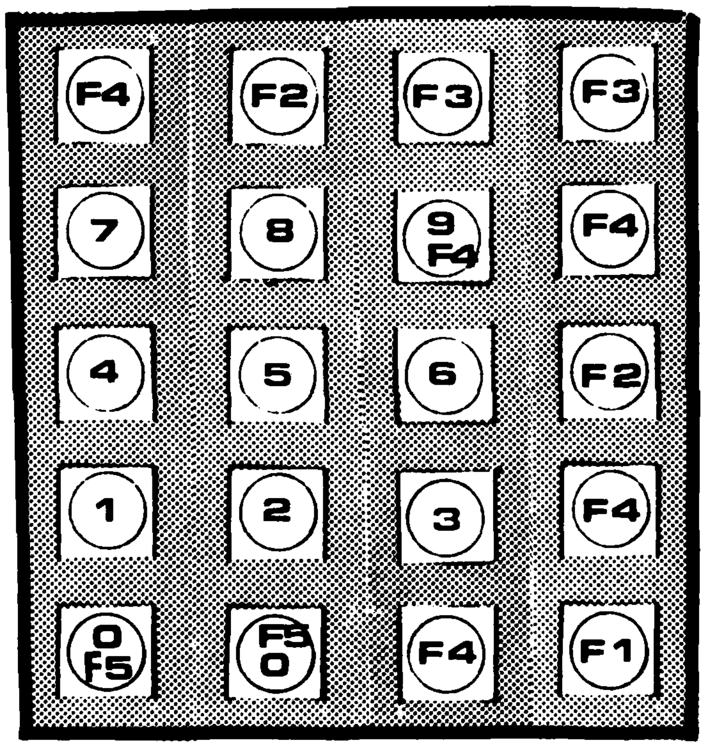


Figure 28. Consensus 5 x 4 keypad.

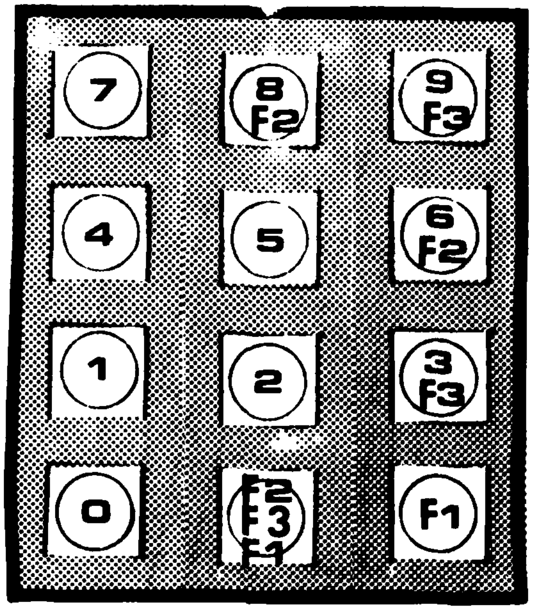


Figure 29. Consensus 4 x 3 keypad.

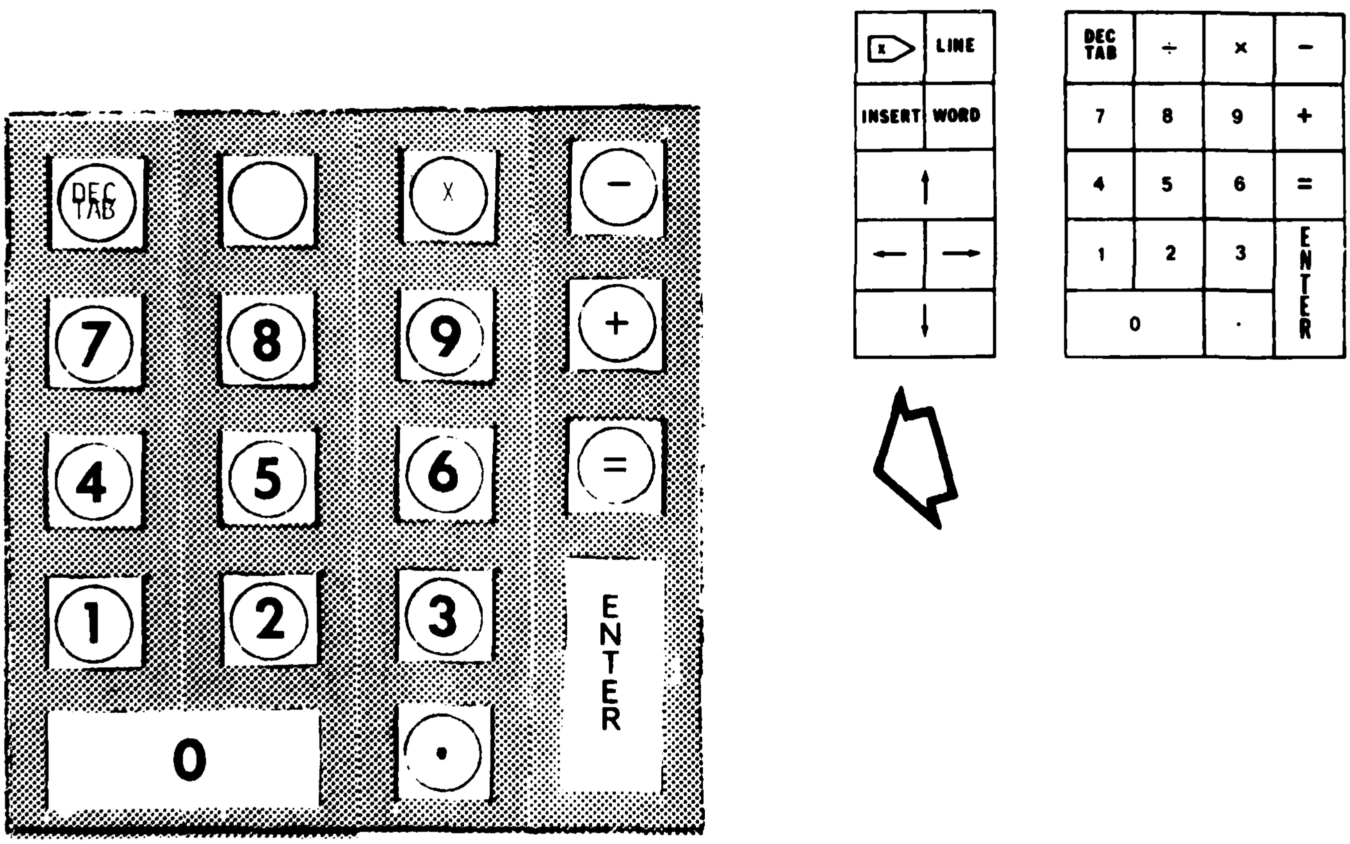


Figure 30. The HASCI keypad.

The most-used function, ENTER, uses a double-size key in the lower right-hand corner of the pad, with 0 also bridging two keys. A separate little keypad, immediately left of the numeric keypad, carries the cursor control in a cruciform array with some control functions above these four keys. The up and down cursor keys are double-size.

Multipurpose Keys

We have already discussed briefly whether keys should have more than one meaning or function (depending on preselection of a mode, or on certain codes or logical sequences of data entry). Except for the most basic uses of communication and entry of numeric information, the assignment of more than one function to single keys is necessary with a restricted keypad. The approach of using chords (i.e., simultaneous, multiple keypresses) will be discussed. The use of multipurpose keys requires sequential entry to change key mode, or the use of shift keys. Desautels (6) points out some of the advantages of ambiguous data entry that depends on context and software for decoding: mostly, the simplicity and avoidance of errors of entry (at the cost of inefficiency of data input from the system standpoint). In its system brochure, Observational Systems, Inc. (16) allows the labeling of a given key by means of a built-in program. Up to 16 characters can be assigned to a key, in addition to its default interpretation, when used with a time-and-motion-study smart clipboard. Any key so assigned displays its label on the unit's LCD when it is pushed.

Fletcher (7) suggests that multimode keys (or the shift of an entire keypad to another mode) must show the operator that the alternate mode has been selected in some other way than just the final appearance of the output. A clear indication of the mode is especially important when speed is important in data entry, as it often would be in combat. Few keypads indicate the mode in other ways than the display. The Epson QX-10® uses small lights to indicate the mode. This registration process is reasonably foolproof for symbolic entry, but not for function entry in which an explicit display seldom accompanies the input of the function. No empirical evidence was found to evaluate specific methods of providing such feedback. Many full keyboards provide information on mode selection with a shift or function key that can be pressed to lock and pressed to release. This approach is of little use on a hand-held keypad designed for input under adverse conditions, unless the keys are of the size and travel found on full computer keyboards.

OTHER ISSUES IN KEYPAD LAYOUT

Templates Versus Labels on Keys

A concern in keypad layout is whether to provide multiple-input keys, special assignable function keys with labels (that indicate the different states that they can assume), or templates that show what these keys mean in different modes. Some templates are overlays, which make them movable labels. These overlays are typically used with membrane or capacitive keypads with no moving parts. Human engineering criteria for the labeling of all keys on keyboards call for explicit labeling on or near the key in question, with no provision for the template concept. Some very new designs in personal computers use the built-in display as the template for function keys. The Radio Shack Model 100 features this labeling strategy for function keys, which succeeds because the keys are below the LCD display.

Chord Versus Single-Stroke Entry

More recently, interest in multiple-stroke chord keyboards has increased. The high amount of information transfer represented by the manipulation of a keyboard or the verbatim reporting capability of a stenotype machine makes this method of transmission of data very appealing, at least at first. Perhaps the most prominent advocate of this method of data entry since the 1950s has been Edmund T. Klemmer of Bell Laboratories.

Klemmer, as reported by Van Cott and Kinkade (14), studied alphabetic entry using 2-key combinations on a ten-key pad and found performances comparable to those of a conventional typewriter keyboard. Multiple keys can be pressed almost simultaneously, (0.03 seconds). A follow-up study, Lockhead and Klemmer (1959), used an 8-key pad with up to 2 keys required for alphanumeric characters, and also chords from 3 to 7 keys to encode 100 different commonly used English words. Again, good results were obtained after about 23 hours of practice with this code scheme.

If the keypad is restricted to one-hand use, 32 different combinations of keypresses are possible, including none at all, leaving 31 different chords. The number of different chords is restricted and the amount of practice to become proficient is high. Studying keystroke combination times for the 31 chords with practiced operators reveals strikingly little difference: range, 281 to 352 ms; mean, 320 ms; standard deviation, 18.7 ms. Other studies indicate little difference among keystroke combination times for numbers of alternatives for 5 to 31 combinations. Input times for the Lockhead and Klemmer code scheme on the average were only 25 ms slower than those for 31 alternatives. Data entry error rates for some stroke combinations are less impressive, in some instances ranging up to 18 percent.

Seibel (13) in a 1964 study compares information rates on a chord system to rates on a conventional (full) keyboard. A chord keyboard of 10 to 20 keys permits five times more information per stroke than with the 40-key typewriter board. Extensive motor training is necessary, and while hunt-and-peck methods are possible with conventional single-stroke keypads, they are not practicable with a chord approach.

Klemmer (8) briefly discussed the chord keyboard in his 1971 review of keyboard entry and provided an example of one layout (17 keys) for possible use by the post office. This illustration is reproduced in Figure 31. This board of 17 keys is only 1 key more than the conventional 4 x 4 single-stroke pad.

Alden and his associates (1) summarized the above findings and add a comment that keypads which minimize the number and distance of finger-reaching movements are capable of the fastest operation, particularly for special-purpose tasks. Stenotype and Word-writer machine operators can achieve speeds of 200 to 300 words per minute (although spoken English averages about 100 words per minute). These machines, with keys somewhat like a toy piano, certainly adhere to this design principle.

Alderman and his associates (2) mention a "handprint" variant to the alpha-dot keypad discussed above. This design is by Sidorsky of the U.S. Army. The operator lays his hand on the keypad and wiggles his thumb and fingers to make coded inputs, in this case the alpha-dot format, but these chords could of course be anything.

SUMMARY

The 4 x 4 keypad's antecedents go back to the 10-key adding machine and to the top-down keypad for telephones. Chord, multiple-press keypads, represent a very different keypad approach.

Paramount among the issues concerned with the layout of keypads is the top-down telephone layout,

```
1 2 3

4 5 6

7 8 9

  0
```

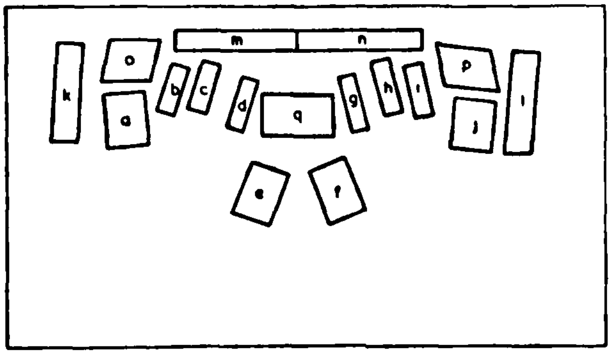
as compared to the calculator bottom-up layout,

```
7 8 9

4 5 6

1 2 3

  0
```



a + f = A	1 + a = 1
a + g = B	1 + b = 2
a + h = C	1 + c = 3
a + i = D	etc
a + j = E	k + f = 6
b + f = F	k + g = 7
b + g = G	k + h = 8
etc	k + i = 9
	k + j = 0

Figure 31. An experimental chord keyboard for mail sorting.
(Conrad & Longman, in Klemmer, 1971)

Since 1955, many studies have been conducted on top-down versus bottom-up keyboard layouts. User expectancies and an advantage in speed of keying in numeric data favor the telephone array, but none of these studies really provides convincing data for adopting the telephone layout over the calculator layout. Calculator and computer manufacturers universally use the bottom-up layout. A number of military and NASA flight data entry systems or weapon systems use the telephone layout. Many of these studies were done before either keypad telephones, microcomputers, or calculators were as widespread as they are now. Consistency of layout is much more important than which of these two layouts is adopted, provided that one <u>is</u> adopted.

Alphabetic data entry requires, with restricted keyboards, some encoding with multiple key entries unless only a few characters are used. The only alternative to multiple-meaning keys is ambiguous entry of alphabetic information, such as that used in telephone keying. Ambiguous entry required restricted input possibilities or software processing of input data by context or other means to resolve that ambiguity, since a given keypress can mean up to three different letters.

Various strategies exist for encoding data beyond the capacities of sixteen keys, such as a matrix look-up, shift-key approaches (some selecting up to <u>four</u> different interpretations for 1 key), and elaborate multiple key logics involving both shift keys and designations of meanings of keys by spatial denotation.

Although there are no standards for layout of keypads, and certainly none for designation or location of function keys on a pad (such as arithmetic or logical operations, or data moves), something of an industry consensus to place these keys above, to the right, and if possible below the numeric keys (invariably bottom-up) with ENTER or (carriage RETURN located at the lower right-hand corner of the array has arisen. Enough agreement regarding function allocation has come about in the past 12 years to permit consensus layouts to be drawn for 4 x 3, 4 x 4, and 5 x 4 keypads to use for further empirical evaluation.

If multipurpose keys are used for data entry, some means of displaying the particular mode that the key or keyset is in should be provided, although just how this is to be done remains for research and development.

Labels for keys are to be preferred over templates wherever feasible. Some new concepts in small microcomputers have effectively used a display area to label those keys. This is a compromise between labeling of keys and templates.

Chord or multiple simultaneous entry keyboards have been of interest for many years, and of course are in wide use in the form of fingerboards on stringed musical instruments. Performance by experienced operators can rival, or in some cases, exceed performance by trained typists on a standard typewriter keyboard. The chief disadvantage of chord keyboards is their relatively high error rate even with experienced operators, when compared to standard layouts, and their unsuitability for untrained operators.

RECOMMENDATIONS

Recommended for future research include:

1. The effects of key matrix size on performance.

2. The effects of function key layout on performance.

3. Determination of optimum layout for alphanumeric data entry using a 4 x 4 matrix keypad.

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6. Desautels, E. J., & Soffer, S. B. (1974). Touch-tone input techniques, data entry using a constrained keyboard. (Report No. PB-231 844/2). Madison, WI: University of Wisconsin.

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Alden, D. G., Daniels, R. W., & Kanarick, A. F. (1972). Keyboard design and operation: A review of the major issues. Human Factors, 14 (4), 275-293.

Data relevant to the keyboard were evaluated from psychological, technical, and promotional literature. This paper reviews the research on the operator-keyboard interface. The important factors concerning keying performance were the operator characteristics, the tasks performed, the equipment, and its environment. Other variables discussed were alphanumerics, speed, accuracy, keyboard slope, and key force displacement.

Alderman, I. N., Ehrenreich, S. L., & Bindewald, R. (1980). Recent ARI research on the data entry process in battlefield automated systems (Report No. 1270). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Sidorsky's study was reviewed concerning the impact of a nonstandard keyboard on the data entry process. The alpha-dot five-key keyboard was compared to the CRT with a standard keyboard. Error analysis and error reduction were also discussed.

Conrad, R., & Hull, A. J. (1968). The preferred layout for numeral data-entry keysets. Ergonomics, 2 (11), 165-173.

This article discusses the 3 x 3 matrix layout of the keypad. The main question is the confusion in the frequent, concurrent use of the phone layout versus the calculator layout. It was found that the telephone keypad arrangement conforms to people's expectations on how the layout should appear. Deininger found that sequences were keyed faster with the telephone layout than with the calculator layout. Conrad tested the 3 x 3 x 1 configuration and found a highly significant advantage in both speed and accuracy with the phone pad. Slower keying was associated with poorer and not better accuracy. The conclusion is that the phone layout provides a more efficient numeral data-entry device than the calculator layout. Both layouts should not be used concurrently. The most favorable layout of the 3 x 3 x 1 configuration is the top to bottom numbering beginning with the 1, 2, 3 at the top and the 0 after the 9.

Cooper, M. B. (1976). The effect of keypad angle of a table keyphone on keying performance. Applied Ergonomics, 7 (4), 205-211.

Ergonomics investigations of the effect of angle of keypad on keying performance are discussed. A brief update of relevant findings is evaluated. It was found that the best angle for the keyphone is about 25°, although a 10-degree deviation either way was not found to be great. The changes in height and position of the keypad determine the best angle. These are determined by using the geometrical method described in the experimental work.

Cooper, M. B. (1979). The effect of feedback on keying performance. Applied Ergonomics, 10 (4), 194-200.

The study looks at the three types of no-travel keypads available on the market today: The membrane, the capacitive, and the conductive keypads. It was found that under normal conditions, auditory feedback on conventional keyphones has no effect on keying performance. This can lessen the decreases in performance produced by the removal of natural sounds and the feel of button operation. Error rates were worse on the no-travel instruments than on the conventional keyphone. The membrane keypad was fastest followed by the conventional keypad. Also, feedback from the handset gave more improved keying performance than from the body of the instrument.

Deininger, R. L. (1960). Human factors studies of the design and use of pushbutton telephone sets. Bell System Technical Journal, 39, 994-1012.

A study was conducted to assess the effects of larger letters and button tops on performance and preference. Button displacement was compared with force held constant and the desirable values of force and travel. The conclusions reached were concerned with the design of a fast, accurate, and convenient push button telephone set. It was found that the operating characteristics of the keyset influenced the keying performance and user preference. In keying performance, there is a range of desirable values within which little deterioration in keying performance is found. The subject preferred a smooth, quiet operation button with a light touch and a moderate travel.

It was concluded that keying performance is influenced by practice, number length, display media, and the familiarity with the telephone number. It was found that memorized numbers were keyed faster than the partially memorized number.

Desautels, E. J., & Soffer, S. B. (1974). Touch-tone input techniques, data entry using a constrained keyboard (Report No. PB-231 844/2). Madison, WI: University of Wiconsin.

This report discusses the problems involved in using a smaller alphabet than the operator normally uses. It focuses on the 12-digit keyboards found on the touch-tone telephones. The major problem is redundancy and ambiguity in the information inputted "as-is." A modified version of the touch-tone called the Cornell Tele-CUPL keyboard and a programming language developed by Strasbourger are discussed.

Fletcher, J. H. (1982). Designing keyboards for the user. Proceedings of the International Conference on Man/Machine Systems. Great Britain: Computing and Control Divison, Institution of Electrical Engineers.

This paper discusses the principles of keyboard design that should be implemented to ensure a user friendly system. The paper is broken down into sections, each dealing with a different principle. These involve the physical considerations, the system-controlled considerations, and the use of coding an individual's keys. Other sections deal with application and implementation of the principles to produce a hand-held keypad. The Teletex Service System is detailed and the various functions available are analyzed and explained.

Hershman, R. L., & Hillix, W. A. (1965). Data processing in typing: Typing rate as a function of kind of material and amount exposed. Human Factors, 7 (5), 483-491.

This study dealt with the keyset entry process of typing. Two limitations were imposed: (1) the breakup of natural sequences in the English text (random words and characters are used for this purpose) and (2) any paralleling or overlapping of processes were controlled by presenting only a small amount of material at a time. It was found that the data were "throughput" faster due to exposure effect and handled faster through the materials effect. When entering information on a display, the amount of information on the display should be sufficient so that the user's paralleling capacities can be used. Three random characters would allow the user to utilize most of this capacity. Six characters would allow words or text to be entered at a higher percentage of the user's maximum efficiency. The better the operator, the more material should be presented. There was no evidence that giving more material than necessary would degrade performance, even when random characters were presented.

Klemmer, E. T. (1971). Keyboard entry. Applied Ergonomics, 2 (1), 2-6.

Recent studies on keyboard entry are evaluated with emphasis on the design question. Speed and error rates are given for varying situations and operators. Topics such as data entry, source documents, ordering of keys, keyboard interlocks, and chord keyboards are also considered. For most people, excluding the highly trained operators, the best design is a two-dimensional matrix with short-stroke, light-touch action and with a separation between keys. The best arrangement of the numeric keyboard is the 3 x 3 x 1 matrix with 1, 2, 3 across the top row.

Lee, W. A., & Snodgrass, G. (1958). The relation between numbering preferences and performance on a ten-button keyboard. [Summary in The American Psychologist, 13 (7), 424-425.] Presented at Sixty-Sixth Annual Convention of the American Psychological Association, Washington, D.C.

The hypothesis was tested that keying performance would be improved if the keys were numbered according to the preferences or expectations of the operator. Two special configurations of keys were tested: the rectangular and the circular configuration. In each case, the operators used two keyboards, one which conformed and one which did not conform to their numbering preferences. The results indicated that keying performance was affected by numbering pattern, amount of practice, and individual differences, but not by numbering preferences. It was concluded that in general, numbering preferences are not valid predictors of keyboard performance.

Litterick, I. (1981, January). QWERTYUIOP--Dinosaur in a computer age. New Scientist, 89 (1235), 66-68.

The fastest way to put information on paper is by a chord keyboard. The problem is the ambiguities encountered when the shorthand is transcribed into English. It is faster only when the information content on each chord is greater than one letter. Other means have been developed such as the Microwriter by Cy Enfield; the Antel Technique, by Tom Steward; and the one developed by Nathaniel Rochester and Frank Bequaert at IBM.

Lutz, M. C., & Chapanis, A. (1955). Expected locations of digits and letters on ten-button keysets. Journal of Applied Psychology, 39 (5), 314-317.

This study found that people expected to find numbers in the telephone arrangement. They also expected a similar arrangement, from top to bottom, of the alphabetic characters. These keys were ordered with two or three letters on each key. Other arrangements of alphabetic characters and numerals were discussed.

Montgomery, E. B. (1982). Bringing manual input into the twentieth century: New keyboard concepts. Computer, 15 (3), 11-18.

The traditional finger stroking motions are inefficient. It is more natural for the fingers to slide, wipe, or sweep across a smooth surface. The best wipe-motion keyboard out today is the Touch Activated Switch Arrays of Santa Clara, California. The wiping motion on the keyboard implies a higher keyboard use. The efficiency potential, arrangement of keys, stroke ratios, and the potential uses of this keyboard are also discussed.

National Aeronautics and Space Administration, Division of Public Affairs (1980). Aboard the space shuttle. Washington, D.C.: Author.

This booklet discusses the flight of a space shuttle from preparation and launch to the re-entry landing and recovery. It addresses some of the problems encountered during the trip. These include weightless conditions, menu, diet, sleeping arrangement, exercise, and hygiene considerations. The shuttle services a variety of functions. These involve freight carrier, repair shop, science lab, factory and deliverer of supplies. EVA procedures, spacesuit design and function, and the engineering of the "space crane" are also detailed. From the shuttle lab, pollution and fish populations can be monitored and the manufacturer of perfect crystals and pure vaccines can be accomplished.

Powers, I. E. (1976). A remote data entry system for military use. UK: The Plessey Co., LTD., Plessey Radar.

The size of the keyboard depends on the analysis of the results of the message transmission requirements. The error detection and correction factor depends on the produced error rate of the person and on the error tolerance of the system. The asynchronous and polled transmission systems are defined and compared. Also discussed are the means to determine channel utilization for both types of transmissions and the probability of a data clash. From this probability, it was determined that more messages are lost due to bit errors than from data clashes.

Rutkowski, C. (1982, October and November). An introduction to the human applications standard computer interface, Part 1 and 2. BYTE, 7 (10 and 11), 291-310 and 379-422.

Rutkowski begins by discussing the necessary functions for a screen editor. The most desirable functions should be placed directly on the keyboard with dedicated function keys. The more complex functions can be assessed by using control-letter functions for access to specialized menus. The problem of deleting a file by mistake is corrected by a special query to confirm the action and its consequences. The undo key is also discussed. HASCI allows a change in function by activating the appropriate control and the recall of the prior function. Format codes modify the text directly, allowing a user to see the text format on the screen before printing a hard copy. Different help menus, control keys, and file controls are also discussed.

Seibel, R. (1972). Data entry devices and procedures. In H. P. Van Cott & R. G. Kinkade (Eds.), Human Engineering Guide to Equipment Design (rev. ed.) (pp. 311-344). Washington, D.C.: U.S. Government Printing Office.

A comparison is made of the chord keyboard and the conventional keyboard. A chord keyboard of 10 to 24 keys permits the entry of 5 times more information per stroke than a 40-key single-stroke keyboard. There is a problem in training time in the memorization of chord meanings. Extensive motor training is required to enter chords quickly. Also there is some difficulty in translating phonetically-based codes into English. The closer the message approximates the normal sequences of characters in English, the faster the message can be keyed. The "Raid-type" system is discussed, plus the inclusion of an error key which erases one word at a time with each depression.

The chord response data suggests that reaction time increases with the information per response up to about 3 bits, but beyond this value any increases in information have little effect on response time.

Smith, S., & Goodwin, N. C. (1971). Alphabetic data entry via the touch-tone pad: A comment. Human Factors, 13 (2), 189-190.

This study investigates the use of the touch-tone pad to communicate information to a speaking computer. The phone pad consists of only 12 buttons, making the entry of alphabetic material ambiguous since several letters represented on each button. Various techniques of double keying have been developed but they are difficult to learn and result in high error rates of data entry, even for trained users. The size of the keyboard depends on the type of material and the computer program utilized. When single keying is used, each alphabetic input is reduced to a numeric code equivalent. Confusion due to numeric code of an alphabetic input was discussed. It was found that the numeric-code confusion for alphabetically different names is rare and occurs less often than when names themselves are confused. When two names are in fact the same, they will be duplicated whenever this input mode is used, whether double keying or single keying. The conclusion was that single-stroke keying of letters on a touch-tone pad was a means of entering names to a computer.

Staff. (1982, September). Time study manual. Redmond, WA: Observational Systems, Inc.

The OS-3's capabilites and merits are discussed. Each alphabetic key may be assigned a label up to 16 characters in length. The assigned labels are stored in memory and written on a keyboard overlay. The full labeling eliminates the need to memorize arbitrary associations between keys and elements. The labeled keys are assigned the three work elements: (1) working, (2) idle, (3) not coded. The OS-3 can generate a random or fixed order for coding study units on each tour.

Taylor, R. M., & Berman, J. V. (1982). Human Factors in aircraft keyboard design: Standards, issues and further evidence relating to gloves and key characteristics. Paper 24 in AGARD Conference Proceedings No. 329: Advanced Avionics and the Military Aircraft Man-Machine Interface.

Data entry factors influencing performance include keyboard positioning and layout, key size, actuation force, keyboard travel, visual and tactile feedback, and key separation and barriers. Other influencing factors were discussed. The report summarizes the issues of aircraft keyboard design and the results of recent research by the RAF.

Warner, P. D., & Clearfield, F. (1982). An evaluation of a computer-based videotext information delivery system for farmers: The green thumb project (NTIS PD82-190273). Lexington: University of Kentucky, Cooperative Extension Service, Department of Sociology.

A new communication delivery system in which information was transmitted over telephone lines and displayed on home television receivers was discussed and developed. The Teletext, Videotext, Prestel, Teleplan, and Green Thumb systems were discussed.

A system utilizing the Green Thumb concept was set up to provide agricultural information for farmers. What this entailed and how it was set up was discussed. The Green Thumb Box was a reliable and low-cost electronic box to receive, store, and display information on the TV screen. The system provided weather, maps, and daily market prices of commodities. Training, hardware, and software requirements were discussed. Also discussed were the problems encountered in the system such as inaccuracy and unreliability of reports, problems with future pricing, and equipment failure.

It was recommended that this type of system be implemented but that research be continued on the impact of the system and on methods for its improvement.

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